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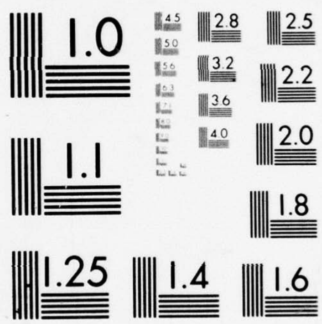

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EXCEDE/SWIR Ion Mass Spectrometer - An Instrument Description

ALAN D. BAILEY

6 January 1978

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This research was sponsored by the Defense Nuclear Agency under Subtask K11BAXHX504, Work Unit 04, entitled "Ion Composition Measurements to Define the Physical Causes of Equatorial Ionospheric Irregularities."

AERONOMY DIVISION PROJECT 2310
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AIR FORCE SYSTEMS COMMAND, USAF

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FOR THE COMMANDER

John Howard

Chief Scientist

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The DNA/AFGL EXCEDE/SWIR rocketborne electron-accelerator experiment was launched from Poker Flat Research Range, Alaska, on 28 February 1976. This report presents the positive-ion mass spectrometer that was part of ~~this~~ experiment. A quadrupole mass filter with a specially designed ion collection configuration is described. Special attention is given to the problem introduced by high positive vehicle potentials which result from the high emission currents of the electron-accelerator. A comprehensive ion mass scanning → next page

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20. Abstract (Continued)

program is described and important instrument parameters are specified. Typical data is included only to illustrate instrument performance.

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EXCEDE/SWIR Ion Mass Spectrometer—An Instrument Description

1. INTRODUCTION

The DNA/AFGL EXCEDE/SWIR rocketborne electron-accelerator experiment was launched from the Poker Flat Research Range, Alaska on 28 February 1976 at 0546:40 into a quiet night atmosphere. A Sergeant rocket engine carried the 32-in. diameter 1700 lb instrument payload to an apogee of 99 km. A 3 kW (3 kV at 1A) pulsed electron beam was initiated at approximately 90 km on ascent, continued through apogee and survived to approximately 75 km on descent. The resulting experiment time was approximately 100 sec.

The purpose of the experiment was the measurement of the spatial, spectral, and temporal nature of visible and infrared atmospheric emissions induced in the atmosphere by a pulsed energetic electron source. Payload based instruments included: 34 photometric-radiometric instruments recording data in two viewing aspects, a visible spectrometer, a plasma-frequency probe, and a positive-ion mass spectrometer. The vehicle was aligned with the geomagnetic field by an ACS system. Ionization rates and charge transfer processes were examined by the positive ion mass spectrometer.

This report presents a functional description of the positive-ion mass spectrometer that was built for this experiment. No attempt is made to present instrument design particulars since these are available elsewhere. Neither is any

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attempt made to discuss or interpret the data acquired. Such discussion is beyond the scope of this report and results of analytical efforts will be reported elsewhere.

2. GENERAL DISCUSSION

2.1 Mass Spectrometer

The EXCEDE/SWIR ion mass spectrometer (IMS) was a quadrupole mass filter of the same general type used by AFCRL in high altitude (>100 km) ion/neutral composition studies since 1972. It was positioned approximately 10 in. radially outboard of the vehicle center, protruding slightly forward of the payload structural front plate, and level with the electron accelerator muzzle. The accelerator was centered in the forward end plate of the 32-in. diameter vehicle.

Figure 1(a) shows the essential elements of the IMS in schematic form. The analyzer/detector section consists of: a set of inlet grids, an ion beam skimming orifice, a quadrupole filter assembly, a low sensitivity ion-collector grid system, a high sensitivity detector, and an electron multiplier (EM). The analyzer housing is a stainless steel cylinder 18-cm long, and 16-cm in diameter. All analyzer components except the EM are centered along and about the housing axis. The several grids and parts were designed to provide both the capability to bias the instrument in a manner to offset the effects of a retarding vehicle potential, and to measure the current density at several points in the sample stream.

Electronics for excitation and signal amplification were contained in a pressurized cylindrical extension. This results in a single, nominally cylindrical package with the sampling aperture at one end and the power/data connector at the other end.

The instrument was equipped with a vacuum tight ejectable cap over the sampling aperture. The analyzer chamber was evacuated and held at less than 10^{-4} torr until after launch by a small, continuously operating, ion holding pump. The pump was included in the instrument along with a NICAD battery, to permit pumping during shipping and handling. The pump was turned off just prior to launch, and the ejectable cap was removed in flight, above 70 km, simultaneously with other similar operations on the other instruments.

2.2 Special Considerations During Operation

The emission of a high current electron beam causes the accumulation of a high positive charge on the vehicle. This vehicle potential is offset only by such electron current as becomes available from the plasma and from the reflected energetic electron beam. In order to attract positive ions through the vehicle

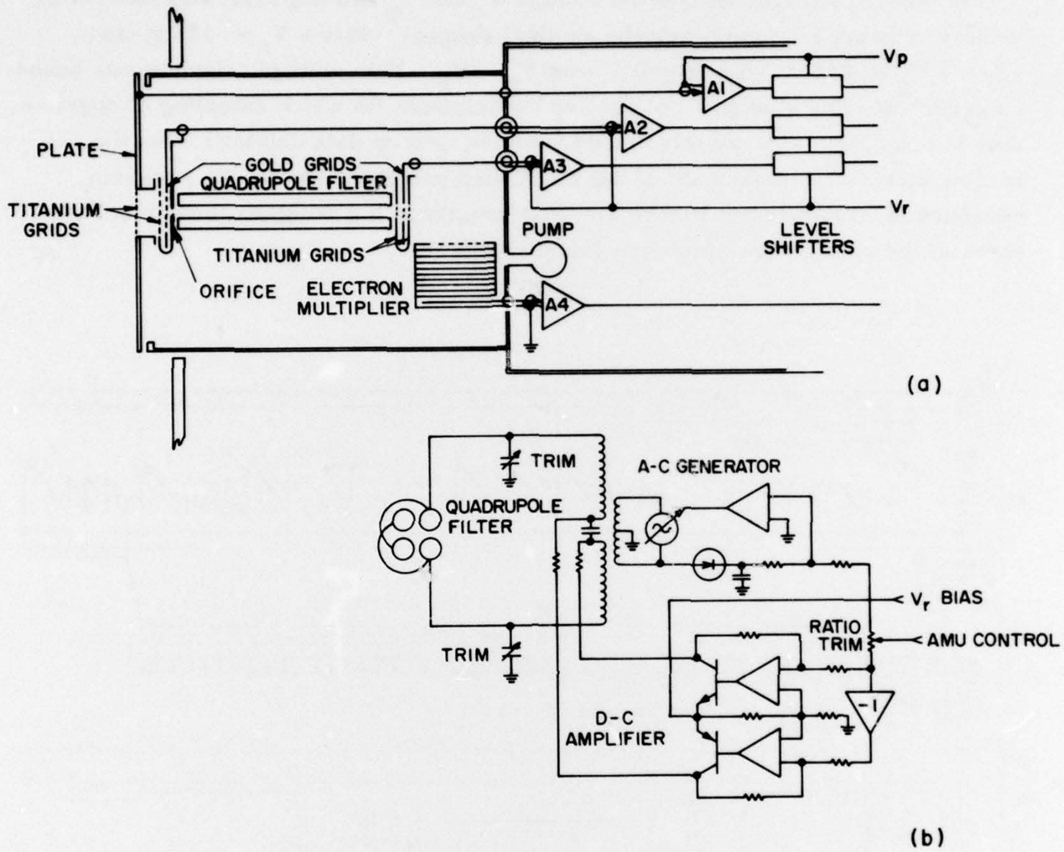

Figure 1. EXCEDE IMS SCHEMATIC ILLUSTRATIONS (a) showing quadrupole filter, ion detector and signal processing concept and (b) showing quadrupole exciter ac/dc control concept

potential field to the IMS, highly negative biases are required internally and at the sampling inlet. First, to directly offset the ion retarding vehicle potential, V_v, the entire analyzer assembly was referenced to a retarding offset bias voltage $|V_r| > |V_v|$. Secondly, a sheath field penetrating bias V_p was applied to the exposed 16-cm diameter forward surface (including the 2.5-cm grid/aperture at the sampling end of the instrument). The greater voltage $|V_p| \gg |V_v|$ is essential in order that the vehicle's retarding field may be penetrated.[1]

1. Sherman, C., and Parker, L.W. (1970) Potential Due to a Circular Double Disk, Res. Paper No. 143, AFCRL-70-0568.

In the EXCEDE/SWIR IMS the voltage V_r and V_p are negative with respect to vehicle, and programmed over the nominal ranges: -15 v > V_r > -125 v, and -31 v > V_p > -248 v, respectively, with $V_p = 2V_r$. This voltage schedule was based on experience and studies from earlier experiments (in which sampling of negative ions is done from a negatively biased vehicle), and on data obtained from the retarding potential experiments of the PRECEDE project. The V_r/V_p program sequence is illustrated in Figure 2. This programming requires important features in the electronics which are discussed later.

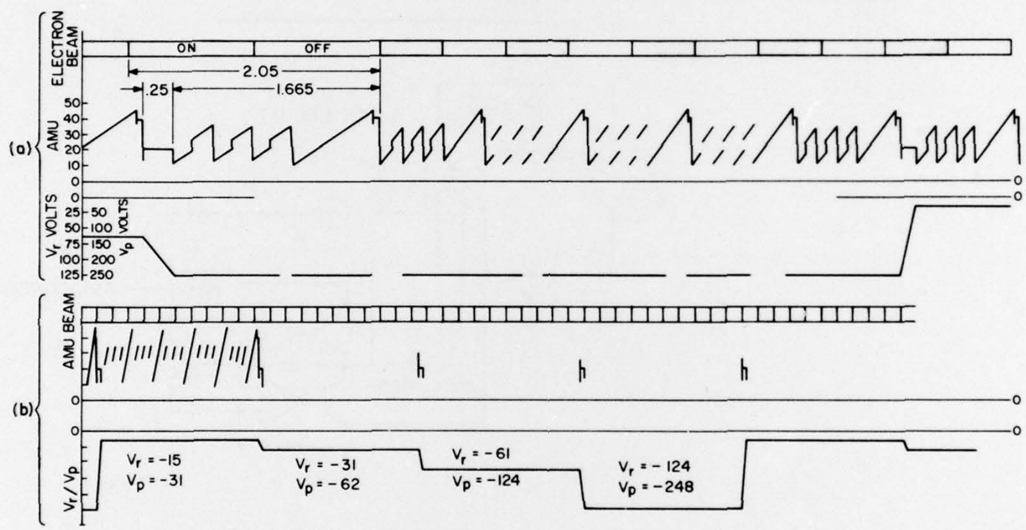

Figure 2. EXCEDE IMS Program

3. DETAILED DISCUSSION

3.1 Inlet Groups

The principle function of the inlet parts group is to attract positive ions from the plasma for subsequent analysis by the mass filter. The front grid/plate assembly consists of the 16-cm diameter exposed forward instrument surface (stainless steel), with a 2.5 cm-diameter gridded aperture at the center. The bias voltage V_p is applied to this element. The grid is 90 percent transmission etched titanium.

The sampling grid is a 52 percent transmission etched gold grid, shielded by a 90 percent transmission etched titanium shield grid and by the stainless steel

orifice plate behind it. Approximately one half the total available inlet current is collected by this grid and fed to the input of a bipolar log-conversion amplifier. The grid diameter was 2.5 cm. Sampling grid to shield spacing was 0.1 cm. A nominal 1-cm spacing between shield grid and the front grid was established for the convenience of assembly.

The beam skimmer orifice plate restricts ion entry to the mass analyzer to the immediate vicinity of the quadrupole filter axis. Orifice size was chosen for a suitable compromise between sensitivity and mass resolution at

$$D_i = 0.5 \text{ mm} \approx r_o/5 \quad ,$$

where r_o is the quadrupole field radius and D_i is the inlet orifice diameter.

3.2 Detector Groups

The output of the mass filter is directed to two detection elements to expand the dynamic range of sensitivity. A 52 percent transmission etched gold grid shielded by 90 percent transmission titanium grids, intercepts the mass filter output beam permitting direct sample of the filtered ion current. Remaining current passing through the grid is collected by an electron multiplier (EM) (Johnston Labs MM-1, 20 stage). The EM high voltage is set for a gain of about 3×10^4, so that by using logarithmic-conversion current-amplifiers with five decades range each, a combined dynamic range of sensitivity between 10^9 and 10^{10} is possible.

Grid Aperture Diameters are:

Filter Exit/Shield	0.37 cm
Sampler	0.51 cm
Shield No. 2	0.51 cm
Grid Spacing	0.1 cm

3.3 Filter Particulars

The mass spectrometer is a quadrupole scanning mass filter. Essential dimensions are:

Pole Length	$L_p = 11$ cm
Pole Diameter	$D_p = 0.635$ cm
Focusing Field Radius	$r_o = 0.273$ cm
Inlet Aperture	$D_i = 0.05$ cm
Exit Aperture	$D_i = 0.37$ cm

Nominal pole to pole excitation voltages were:

AC Frequency	4 MHz
AC Amplitude Range	225 to 800 Vac peak
DC Amplitude Range	36 to 130 vdc in scan mode
	0 vdc in total ion mode

3.4 Scan Program

The EXCEDE/SWIR electron accelerator was programmed with a 2 sec frame consisting of equal ON and OFF intervals of 1 sec each. See Figure 2(a) (actual flight frame interval was 1.95 sec). The mass filter scan program was designed with a basic "cell" interval of 1.6 sec. This was to provide a deliberate phase drift interval of approximately 10 sec with respect to the 2 sec accelerometer rate. In addition, in order to incorporate a bias effects study, a multiple bias program was employed with each bias interval occupying one phase drift cycle. See Figure 2(b).

Within each 1.6 sec "cell" the mass filter was programmed to scan the range:

$$\frac{m}{q} = \frac{\text{(mass in amu)}}{\text{(charge in electron units)}} = 10 \text{ to } 46$$

once, and the selected ranges $m/q = 13$ to 21 jumping to $m/q = 26$ to 35, three times each. This concept provides, within each 10 sec cycle, a useful sample of each ion species at several points within the electron beam ON and OFF states.

The bias program steps the voltages, V_r and V_p, through four levels at approximately 10 sec each, synchronously with each drift cycle of six mass-scan "cells." At each step transition, the biases are scanned between levels in 0.22 sec, while the mass filter passes all ions with $m/q > 21$ amu. The mass scans were also supplemented with a 0.06 sec sampling of all positive ions with $m/q > 41$ amu once each "cell." Bias levels employed were:

Step	V_r	V_p
1	-15.7 v	-31 v
2	-30.7 v	-62 v
3	-61.3 v	-124 v
4	-124 v	-248 v

V_p was applied to the front grid/plate assembly, and V_r was applied to all other elements except the EM.

3.5 Electronics

Detailed discussions of the electronic circuitry are left to other reports.[2,3,4] Discussion in this report is restricted to description of the function of only those modules/components which are essential to understanding the instrument capabilities and data outputs.

3.5.1 QUADRUPOLE EXCITER – AC

A fixed frequency 4 MHz oscillator with balanced output capabilities in excess of 800 Vac peak is controllable in amplitude over a dynamic range much greater than 5:1. The quadrupole dc voltages are inserted at the center (Vac = 0) of the balanced output transformer. Amplitude of the ac is controlled by comparing the 0 to 10 vdc scan reference with a peak-detected output sample. (See Figure 1(b).)

3.5.2 QUADRUPOLE EXCITER – DC

A high voltage dc amplifier is employed with its output balanced with respect to the bias voltages V_r. Two inputs control this amplifier; a 0 to 10 vdc scan reference, and the bias voltage V_r. The dc amplifier output is injected at the ac transformer split center taps. See Figure 1(b).

3.5.3 BIAS VOLTAGE SUPPLIES[4]

The two bias voltages are controlled by digital logic to provide the outputs described as V_r and V_p. The logic is synchronized with the mass scan controller. The voltage V_p is applied to the inlet plate/grid through the bipolar current sensing amplifier A_1. The voltage V_r is applied to the bias reference input of the quadrupole exciter, to the skimmer orifice plate and shield grids, and through amplifiers A_2 and A_3 to the inlet and detector sampling grids.

3.5.4 DATA AMPLIFIERS A_1, A_2, A_3 AND A_4[4]

All of the current beam sampling amplifiers are functionally transimpedance devices. Amplifiers A_2, A_3, and A_4 are log converters wherein $e_{out} = F[\log (i_{in} + i_o)]$. Amplifier A_1 is quasilinear over selected segments, while A_1 and A_2 accept bipolar input currents. The biased input amplifiers A_1, A_2, and A_3 each consist of a floatable biased converter unit and an output level shifter. These especially adapted circuits are described in AFGL-TR-76-0060.[4] Calibration curves for all four beam sampling amplifiers are given in Figures 3 through 5.

2. Tricon Associates, Inc. (1974) AFCRL-TR-74-0269, Final Report, Contract F19628-71-C-0196.
3. Northeastern University (1974) AFCRL-TR-74-0580, Scientific Report No. 1, Contract F18628-74-C-0042.
4. Northeastern University (1975) AFGL-TR-76-0060, Scientific Report No. 2, Contract F19628-74-C-0042.

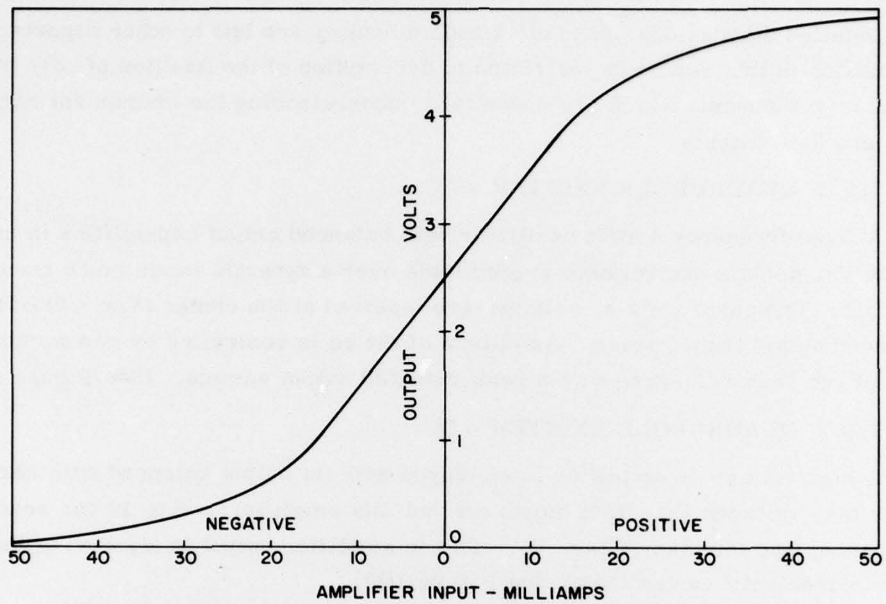

Figure 3. Calibration Curve for Amplifier A1

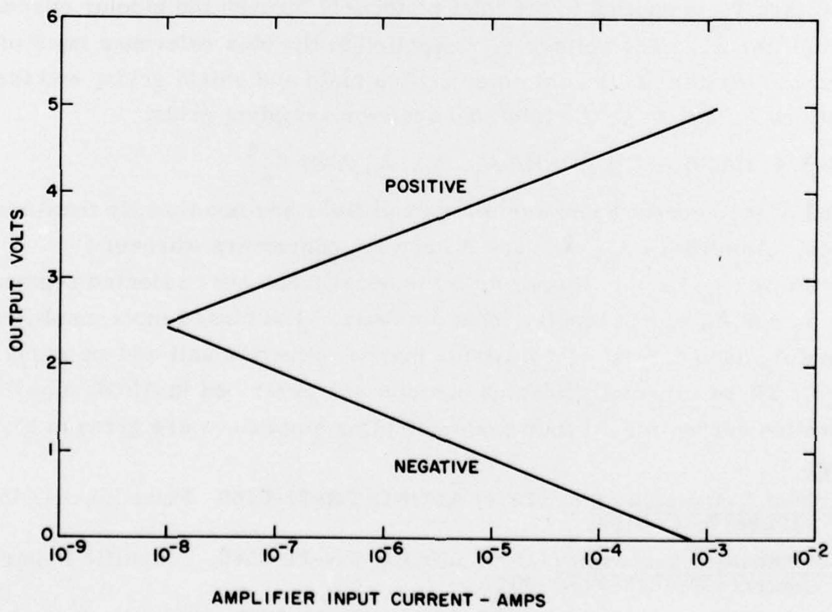

Figure 4. Calibration Curve for Amplifier A2

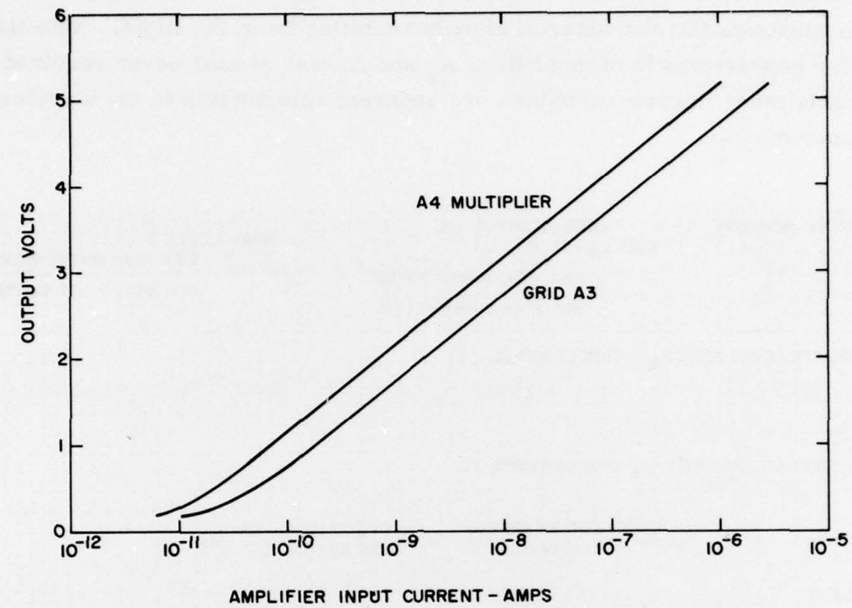

Figure 5. Calibration Curves for Amplifiers A3 and A4

4. TELEMETERED DATA

IMS data telemetered by the EXCEDE/SWIR payload consisted of:

DATA Identification	LINK 3 Channel
A_1	IRIG 14
A_2	12
A_3	10
A_4	11
Bias Monitor	15
Mass Monitor	13
RF Monitor (Quad ac)	Commutated IRIG
HV Monitor (EM)	Commutated IRIG
TC Vacuum Gauge	Commutated IRIG
Diagnostic Monitors	Commutated IRIG

The first six monitors are essential to complete data analysis. The remaining (commutated) monitors are instrument diagnostics which would have been useful

in the event of MS malfunction. Figure 6 shows a segment of the flight data selected to illustrate the character of signals resulting from the flight. Note that the bipolar characteristic of amplifiers A_1 and A_2 was almost never required. Innumerable other interrelationships are apparent contributing to the usefulness to the experimenter.

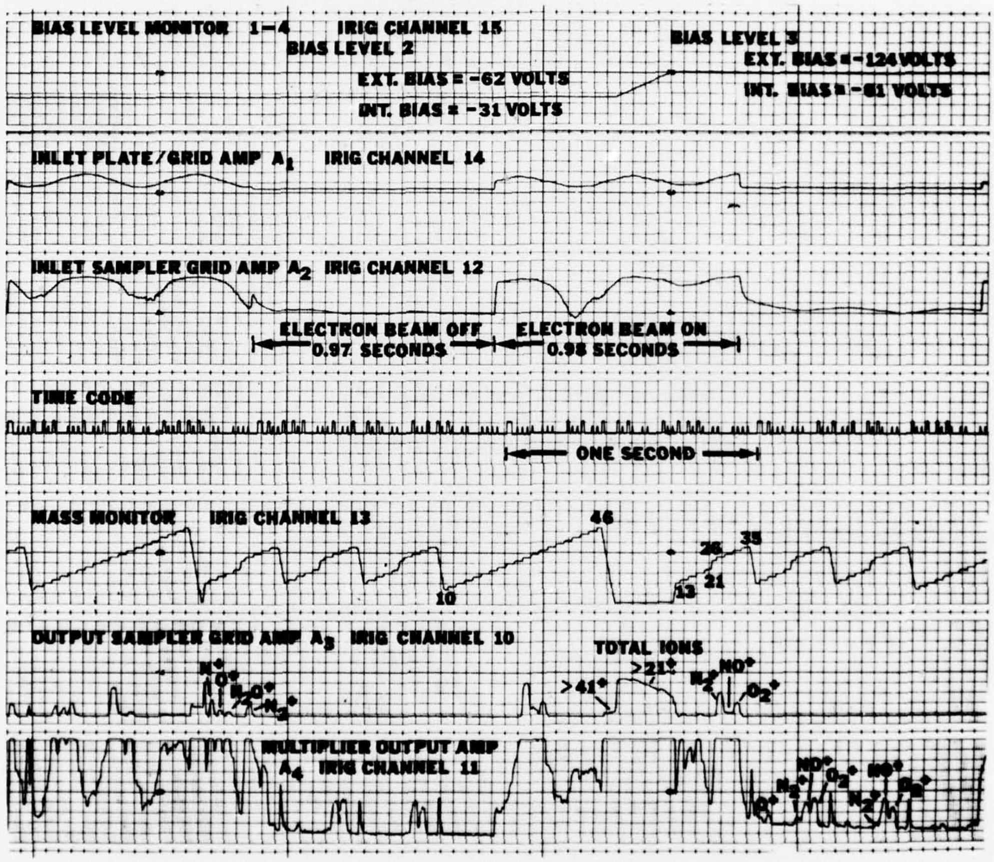

Figure 6. Flight Data Segment

5. PERFORMANCE[5]

The positive ion mass spectrometer was initiated simultaneously with the electron gun turn-on and recorded data of excellent quality for approximately

5. O'Neil, R.R., Stair, A.T., Jr., Ulwick, J.C. and Narcisi, R.S. (1976) EXCEDE/SWIR Experiment, AFGL Quick Look Report.

120 sec in the altitude range of 68 to 99 km (data sample shown in Figure 7). The sensitivity of the instrument was sufficient to measure from the low ambient nighttime ion concentrations to densities on the order of 10^{10} cm^{-3}. The actual measurements recorded densities from approximately 10^{1} to 10^{8} ions cm^{-3}. An initial analysis of the data indicates that the vehicle potential of the electron emitting payload was seldom greater than 60 v positive with a potential substantially less than this magnitude for the major portion of the experiment. Complete interpretation of the data is anticipated to determine:

(a) The time dependent buildup and decay of ionic species as produced by the pulsed electron beam.

(b) The ionization content of the near field plasma.

(c) The variation of the time dependent abundances as a function of altitude.

(d) Ionization production yields, charge transfer processes, and steady state concentrations of the beam induced positive ions.

The rocketborne pulsed electron beam technique, as demonstrated in this experiment, provides a controlled ionization source capable of measuring detailed ionic production and loss processes in addition to the steady state concentrations typically measured in natural events (day/night atmospheres, PCA's, aurora, etc.).

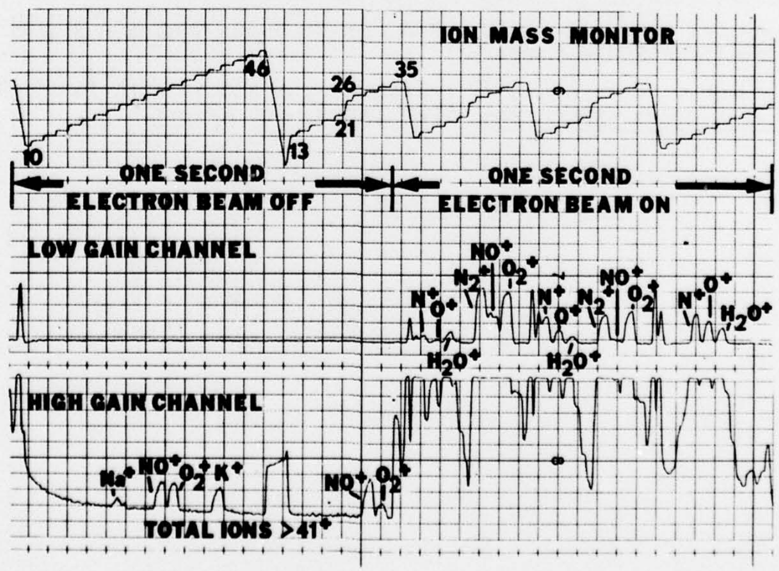

Figure 7. Flight Data Sample in the 68 to 99 km Altitude Range

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1. Sherman, C., and Parker, L.W. (1970) Potential Due to a Circular Double Disk, Res. Paper No. 143, AFCRL-70-0568.
2. Tricon Associates, Inc. (1974) AFCRL-TR-74-0269, Final Report, Contract F19628-71-C-0196.
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5. O'Neil, R.R., Stair, A.T., Jr., Ulwick, J.C. and Narcisi, R.S. (1976) EXCEDE/SWIR Experiment, AFGL Quick Look Report.

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